

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

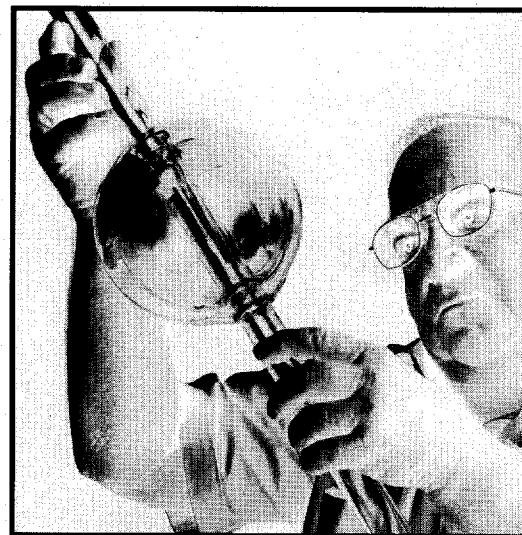
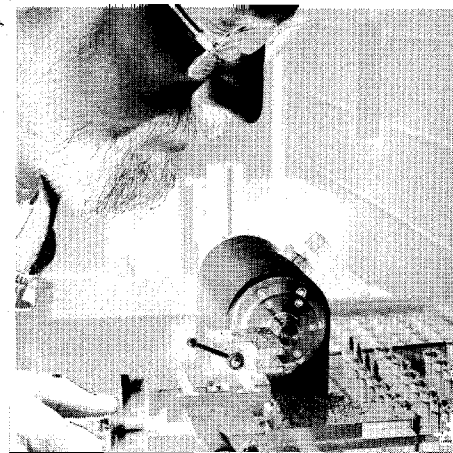
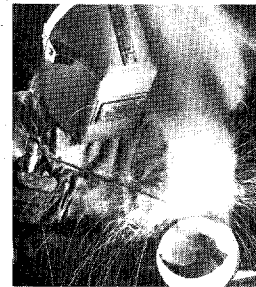
MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

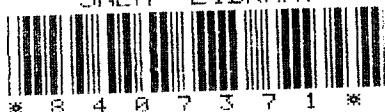
MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES

MANUFACTURING
TECHNOLOGIES



SNLA LIBRARY



SAND91-0744
0003
UNCLASSIFIED

00/91
28P

STAC



Sandia
National
Laboratories

Introduction



The CL805 Capacitor Winding Machine was developed for high accuracy winding.

Sandia National Laboratories' Manufacturing Technologies Directorate develops technologies and processes to assure manufacturability of products that are designed and developed by Sandia. We work shoulder-to-shoulder with research and design staff early in the development cycle to meet the needs of our customers. Our staff and facilities contribute to and support all project stages: concept formulation, design, process development, prototype fabrication, test and evaluation, and follow-on production.

Most products that are designed and developed by Sandia are manufactured by industry and the US Department of Energy's production agencies, and our involvement continues throughout that production. Our strength comes from our people, with their diverse backgrounds and skills, and our broad-based, conveniently located facilities.

What we do

Our mission is to develop techniques, processes, and unique equipment to satisfy prototype fabrication and subsequent production needs of Sandia in a safe and environmentally conscious manner. We assist customers in finding available commercial solutions; when these are not available, we perform supplemental development activities that include

- **Process development:** Develop, understand, and characterize the processes necessary for production and develop specifications for those processes.
- **Prototype hardware:** Fabricate or procure prototypes for process evaluation and design demonstration.

- **Producibility assessments:** Evaluate the design and production processes to identify producibility improvements.
- **Quality:** Develop appropriate quality methods and controls to assure that requirements are met.

Our capabilities

The services that we provide are grouped into three major technical areas of process development and fabrication:

Electronics

- Solid-State Devices
- Hybrid Microcircuits
- Printed Circuits
- Electronic Fabrication
- Measurements and Standards

Materials

- Metals
- Ceramics
- Glass
- Thin Films and Brazing
- Polymers, Adhesives, and Composites

Mechanical

- Machining
- Manufacturing Engineering
- Computer-Aided Manufacturing and Stereolithography

We have internal technical resources for engineering applications and development in each area and have transferred these technologies to and from industrial facilities throughout the United States. In a manufacturing-like environment, craft specialists, process development engineers, scientists, and technicians work together to suggest and evaluate options that best meet customer needs.



Thin-film microcircuit fabrication.

How we do it

To improve our skills and performance, we interact with other technical specialists and participate in educational programs. An internally operated 10,000-hour apprentice program for craft specialists consisting of on-the-job training, process theory, and other technical course work is a key to maintaining our exceptional capability. We attain concurrent engineering by our craft specialists and technicians working directly with customers and process engineers.

We operate a large array of carefully maintained machines and closely controlled processes that are enhanced by the pride and skill of the staff. Our operations range from microscopic to massive, intricate to simple, conventional to highly specialized, and office to clean room. We continually strive to increase the efficiency, robustness, and effectiveness of our processes while reducing hazards, wastes, and environmental impact.

We are dedicated to satisfying the cost, schedule, and performance requirements of our customers, and pledge to continuously improve through quality practices. If you would like to know more about our capabilities and how we can help meet your needs, please call the Director of Manufacturing Technologies (505) 844-8035.



A Casting operation

Solid-State Processing

The Solid-State Processing group provides the process expertise and fabrication support needed by engineers and scientists to develop new or improved piezoelectrics and Group III-V semiconductor components for a wide variety of sensors, resonators, and optoelectronic applications. Our staff is experienced in all phases of solid-state processing: substrate preparation, thin-film deposition, submicron photolithography, micromachining, precision plating, wet and dry etching, and device packaging and evaluation. We develop, modify, or adapt processes to suit the needs of our customers. Our activities are centered in the Prototype Processing Laboratory (PPL) and the Quartz Device Laboratory (QDL). We work closely with designers from the conceptual stage of a project through prototype, test, and transfer of the technology to a manufacturing facility.

Major resources

PPL

- Class 100 clean room dedicated to the processing of solid-state prototype devices with principal emphasis on Group III-V semiconductor materials, such as GaAs.
- Single- and double-sided mask aligners (0.6- and 2.5- μm resolution).
- Evaporative electron beam metallization using lift-off techniques for ohmic contacts and interconnects.
- Sputtering system.
- Vacuum-tube furnaces.
- Reactive ion etching (RIE) of dielectrics and metals.
- Plasma-enhanced chemical vapor deposition (PECVD).
- Photomask design.
- Linewidth measuring systems.
- Precision gold plating.

QDL

- Ion sweeping system for producing radiation-hard quartz material.
- Substrate lapping and optical polishing (a 400 ft² Class 100 work area with 10 workstations).
- YAG laser precision tuning system with a focused 2- μm beam.
- 24-position carousel for gold metallization and sealing of quartz resonators (used for semiproduction runs).
- Vacuum furnace for sealing component packages.
- 30-position slew tester (temperature and frequency).
- Microcomponent robotic assembly systems.
- Mass spectrometer helium leak detector.
- Precision gold plating.



Prototype Processing Lab (PPL) mask aligner station.

Selected accomplishments

PPL

- We have demonstrated an optical tamper sensor that consists of an epitaxially grown GaAs/AlGaAs substrate and an integrated laser diode that is coupled to a photodiode by an organic waveguide. Unique light absorbers, when disturbed by an intruder, change the electrical output signal from the photodiode.
- We have demonstrated an on-chip series-connected GaAs optical power converter.
- An ongoing project is a 3-MHz GaAs resonator that will ultimately include an oscillator circuit on the same chip. The processing entails deep, smooth vertical wall anisotropic reactive ion etching.
- Another current effort is a ferroelectric nonvolatile radiation-hardened memory element.
- A new initiative is a 1-mm³ micromachined quartz MHz resonator and integrated package.
- Other projects include GaAs optoelectronic thyristors, optical logic elements, lasers, photodiodes, and a variety of sensors for detecting infrared radiation, acceleration, and chemicals.

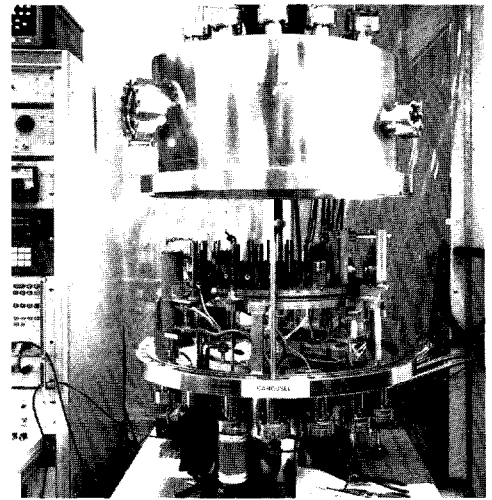
Selected accomplishments (continued)

QDL

- The quartz and piezoelectric device prototype laboratory is capable of producing a few to a few hundred resonators on production-like equipment (the carousel). Manufacturing support processes are characterized and then transferred to industry.
- The facility covers a total of 2000 ft² and provides radiation-hard quartz-based prototype components. Bars are cut from high-purity single-crystal quartz and further refined by sweeping to improve radiation resistance. They are then wafered, lapped, and optically polished to less than two wavelengths of light in flatness prior to photo-lithography, metalization, wet etching, tuning, assembly, packaging, sealing, and testing. Typical finished devices include conventional and strip resonators, accelerometers, rotation sensors, surface acoustic wave (SAW) devices, and other piezoelectric components.
- We produce a wide variety of standard resonators in the 15 to 100 MHz range that are packaged in leadless chip carriers. These premium devices are used where high accuracy and stability are required.
- A quartz digital accelerometer has been developed from wafer preparation through all stages of processing and testing. An accompanying robotic handling system was designed to control assembly of the miniature parts to within 2 to 3 μm .
- We developed the equipment and the procedures for processing radiation-resistant quartz and transferred the technology to industry.



Substrate lapping and polishing lab.



Quartz Device Lab (QDL) resonator plating and sealing carousel.

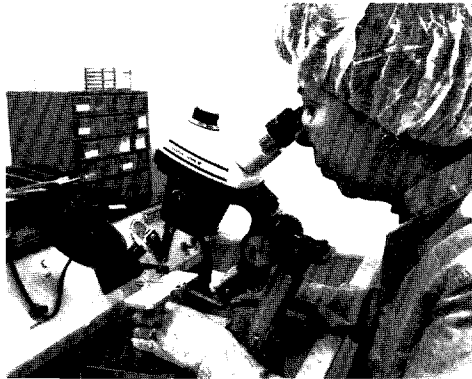


Sandia National Laboratories

SAND 91-0744/7400/f-ia

Hybrid Microcircuits

Sandia's Hybrid Microcircuit group supplies material and processing expertise and prototype fabrication capabilities for a wide variety of hybrid microcircuit applications. We develop manufacturing processes, determine performance characteristics, establish design practices and specifications, and provide opportunities for concurrent engineering on new hybrid designs. We also assist our customers with the physical design and layout of the hybrid microcircuit, help them select the most appropriate hybrid technology for the application, develop new materials and processes, and fabricate prototype samples.



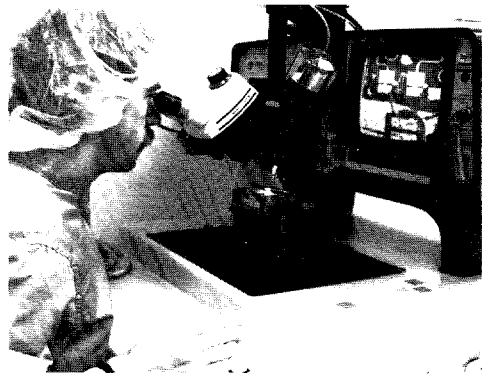
Both eutectic and epoxy die attachment processes are available within the Hybrid Microcircuit group.

Major resources

- Staff trained from PhD to Tradesman level, which allows us to support projects across a wide spectrum of hybrid microcircuit areas.
- A broad range of fabrication equipment, including thick- and thin-film hybrid fabrication equipment, a direct-write Micropen[®], CO₂ and YAG lasers, dc magnetron vacuum coaters, via filling machines, and an isostatic press for fabricating cofired ceramic structures.



A split-field microscope is used by the operator to align a photomask to a previously patterned thin-film conductor pattern.



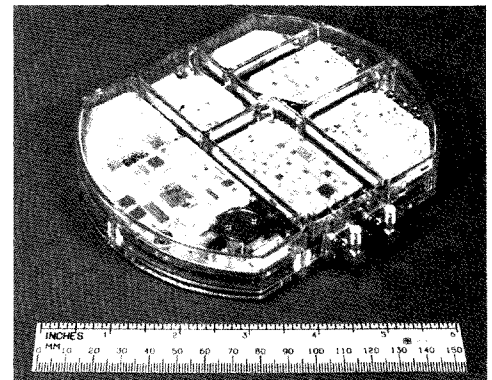
A variety of both manually operated and programmable automatic wire bonders are used to assemble complex hybrid microcircuits.

Capabilities

- Thick-film multilayer double-sided hybrids.
- Thin-film hybrids.
- Chip and wire hybrids.
- Low-temperature cofired ceramic three-dimensional packages.
- Hybrids built on Duroid[®] substrates.
- Semiconductor device packaging.

Selected accomplishments

- Fabricated microwave hybrids for use at frequencies up to 15 GHz on Duroid[®] substrates having 17- μ m thick copper conductors that were patterned to dimensional accuracies of better than 6 μ m. The hybrids contained through-hole and slot vias as well as component cavities for monolithic microwave IC devices.
- Evaluated the thermal-cycle life of surface-mounted LCC packages on ceramic substrates.
- Characterized wire-bonded semiconductor devices in LCC packages to mechanical shock levels greater than 150,000 g.
- Developed concepts for packaging electronic circuits that will be subjected to high-level mechanical shocks.



The precision patterning available using photolithographic processes on thin-film networks is well suited to the fabrication of high-performance radars.

Printed Circuits

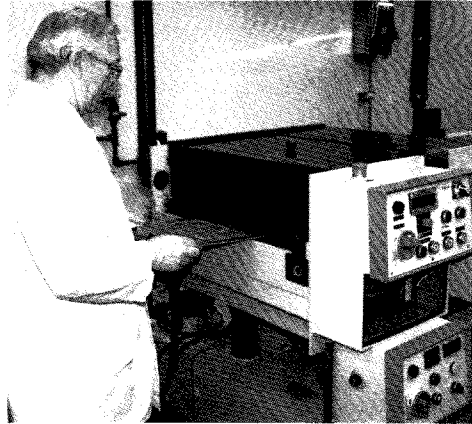
Sandia's Printed Circuit group provides the technology base for the design, development, and production of electrical interconnection devices using organic-based laminates. We provide opportunities for concurrent engineering as well as process and manufacturing development for customers using printed circuit boards, flex circuits, rigid-flex devices, and chemically milled metal foil products. We develop new materials, select the most appropriate material and packaging technology for our projects, and fabricate, assemble, inspect, and test electrical interconnection circuitry. In the Prototype Development Laboratory, we use state-of-the-art equipment to fabricate prototype hardware.



X-ray diagnostic tool used to pinpoint faults on inner layers of circuit boards.

Capabilities

- Develop, fabricate, assemble, and test
 - multilayer printed circuit boards
 - flex circuits
 - rigid-flex devices.
- Environmentally test electronic subsystems, perform x-ray inspection, and test bare boards.
- Provide screen printing, wave soldering, aqueous cleaning, microwelding, and soldering.
- Unique implementation of waste reduction and recovery systems.



Precleaning and fluxing board for hot-air leveling.

Major resources

- Staff trained from PhD to Tradesman level, which allows us to support projects across a wide spectrum of printed circuit areas.
- Our Excellon Direct-Imaging System II allows immediate, direct imaging on printed circuit boards and provides a cleaner image than a photographic process.
- Integri-Test bare board tester.
- Astrophysics Research Corporation x-ray inspection system.



Numerically controlled drill.

Selected accomplishments

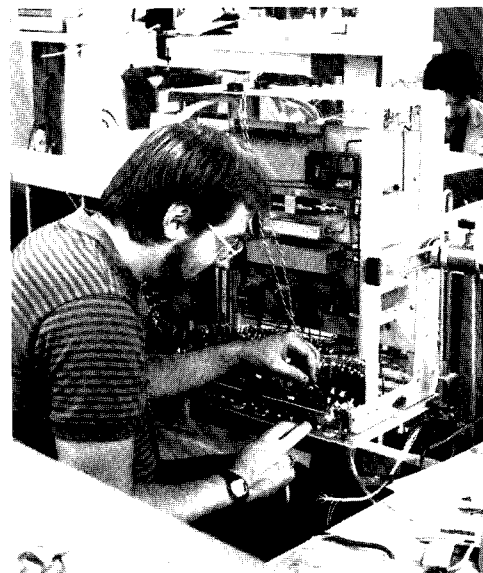
- Developed processes for plating copper onto Duroid[®] substrates.
- Used the direct imaging system for printed circuit board processing.
- Established performance characteristics of interconnect circuits.
- Demonstrated a copper recovery system as well as CuCl_2 and ammonia etching systems for environmentally conscious manufacturing.



Copper plating a substrate material.

Electronic Fabrication

Sandia's Electronic Fabrication group provides electronic equipment design and fabrication for a wide variety of applications. Capabilities include design, an opportunity for concurrent engineering for designers, and fabrication of the designs. We also provide concurrent engineering and prototype magnetic device fabrication for many types of coils and transformers.



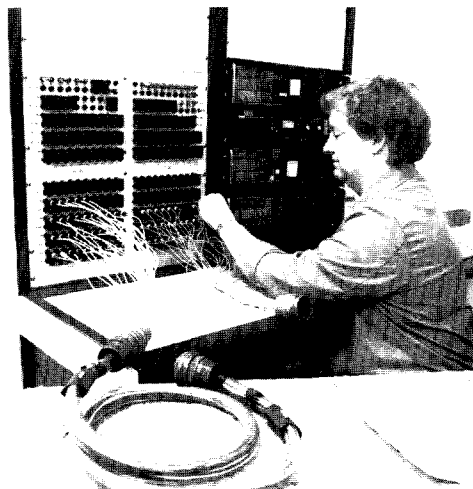
Wiring of an rf test chassis for evaluating fuzing radars.

Our effort includes

- Engineering consultation.
- Review of worksheet or drawings.
- Ordering parts required for process.
- Planning and fabricating special brackets, cases, chassis, and panel engraving.
- Complete inspection services.
- Documentation of design and inspection requirements.
- Assisting engineer with complete systems troubleshooting and final product testing.

Sandia's Coil and Transformer Fabrication effort includes

- Engineering consultation.
- Review of worksheet or drawings.
- Machining unique or commercially unavailable bobbins or winding forms.
- Winding the devices and applying interlayer insulation, encapsulating the device (in-process and after winding), inserting winding taps, and terminating the leads.
- Testing the finished device.



Inspecting a cable using the tester that was designed, fabricated, and programmed in Electronic Fabrication.



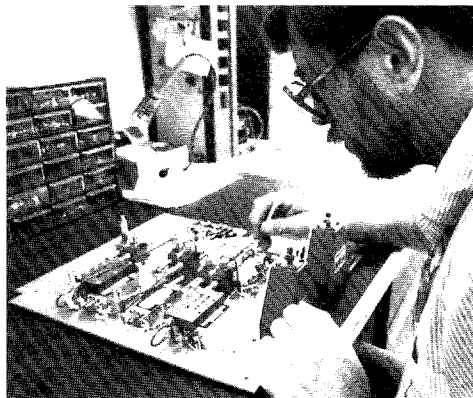
Designing printed circuit boards using a commercial P-CAD software package.

Capabilities

- Lay out printed wiring boards.
- Concurrent engineering.
- On-site and off-site equipment installation.
- Coil Winding Shop can wind devices with ultrafine wire (AWG 55, a fraction of the size of a human hair) to heavy-duty wire (AWG 2 and larger with special setups).
- Our engineers are accessible, making in-process design changes easy.
- Fabricate one-of-a-kind items.
- Develop manufacturing procedures.
- Hand wind when automation is not practical.

Major resources

- Fabrication Shop has a machine shop for mechanical fabrication. We use state-of-the-art computer-controlled equipment to produce items such as engraved aluminum front panels for test equipment.
- Test equipment to evaluate sophisticated interconnected systems. It can measure resistive continuity in the milliohm range and leakage current with applied voltages up to 500 Vdc.
- Computer-controlled layered and toroid winding machines.



Assembling an array of components (isolators, rf switches, equalizers, amplifiers, and semi-rigid coaxial cable) onto a range delay board.

Selected accomplishments

- Designed and built testers that provide liquid-to-liquid thermal shock or thermal cycling with computer-controlled continuous test monitoring.
- Designed and built a tester to measure Seebeck characteristics of thin-film metallization.
- Provided concurrent engineering and fabrication for a wide variety of equipment to support major Sandia projects.
- Coordinated the layout and installation of electronic equipment at major remote Sandia sites such as Kauai Test Facility, Nevada Test Site, and Waste Isolation Pilot Plant.

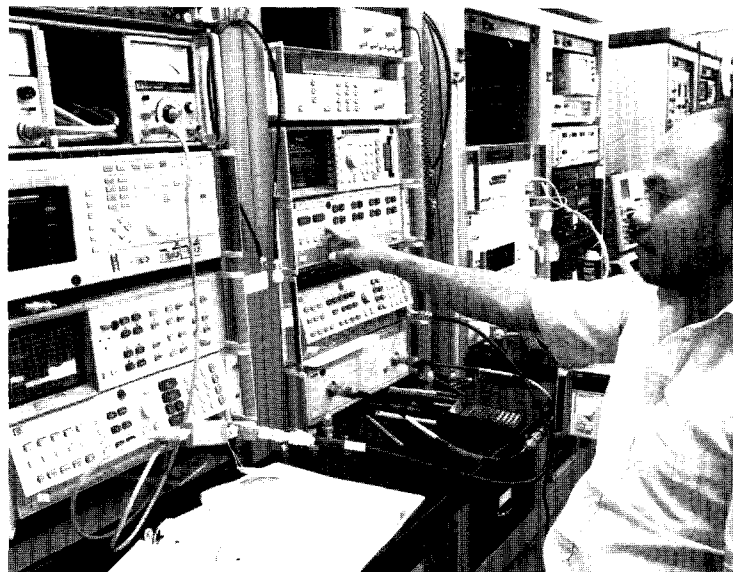


Sandia National Laboratories

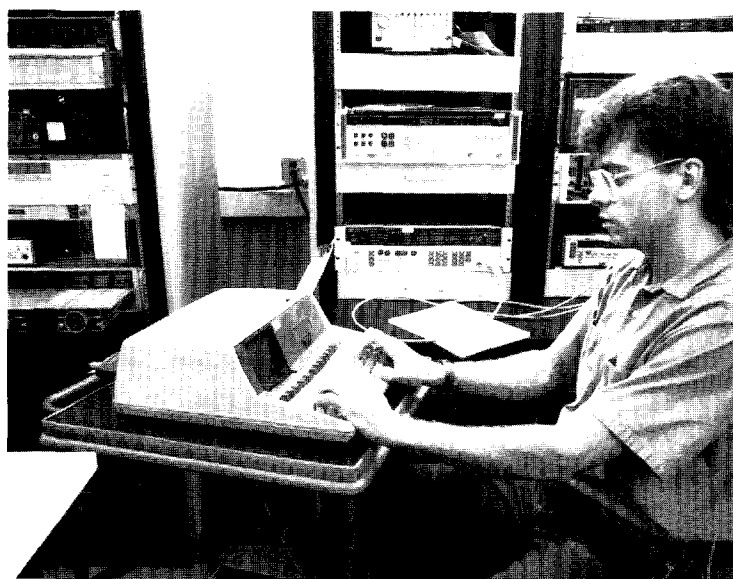
SAND 91-0744/7400/f-1a

Measurements and Standards

Sandia's Measurements and Standards group's main responsibility is to calibrate measurement equipment. We also diagnose, repair, and modify instruments, and help our customers select instruments and interpret data. We label equipment with calibration and expiration dates, and maintain measurement data files.



Automated microwave measurement systems.



Automated frequency system.

Capabilities

• Measurement disciplines, electrical standards:

ac voltage	1 μ V to 1 kV at 10 Hz to 1 MHz
dc voltage	1 μ V to 30 kV
ac-dc current	1 nA to 100 A
capacitance	1 pF to 100 μ F
inductance	10 μ H to 10 H
resistance	1 m Ω to 10 T Ω
frequency	10 mHz to 26.5 GHz
rf power	10 μ W to 1 W
attenuation	to 120 dbm

• Measurement disciplines, instrument repair:

ac voltage	1 μ V to 1 kV at 10 Hz to 1 MHz
dc voltage	1 μ V to 10 kV
ac-dc current	1 μ A to 100 A
resistance	10 m Ω to 100 M Ω
temperature	-100°C to 1200°C
frequency	1 Hz to 1.3 GHz

• Calibration disciplines, physical standards:

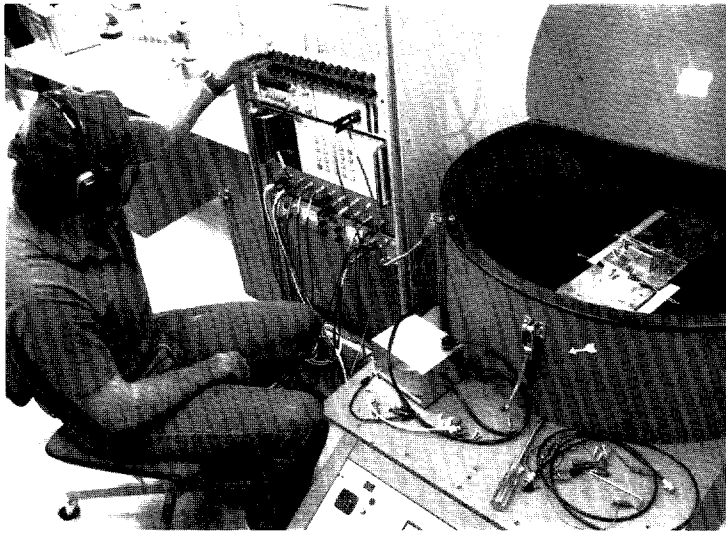
pressure, static	1 mtorr to 10,000 psig gas 1 to 60,000 psig liquid
pressure, dynamic	1 to 1000 psig gas, 90- μ s step 1 to 100,000 psig oil, 7-ms pulse
acceleration, steady	1 to 5000 g
acceleration, shock	1 to 15,000 g, 90- μ s pulse
acceleration, sine	0.5 to 30 g, 5 Hz to 10 kHz
gas flow	1 scfm to 10 scfm air
force, static	50 to 20,000 lb
relative humidity	8 to 98 percent at 5°C to 80°C
dew point	-25°C to 90°C
temperature	-100°C to 2500°C continuous. (Discrete temperatures can also be produced)

• Measurement disciplines, mechanical measurements:

angles	to 360°
diameter	
external	0 to 18 in.
internal	0.007 to 12 in.
optical flatness	10-in. diameter
force	0.002 to 2500 lb
length	
coordinate	78 in. x 47 in. x 39 in.
linear	0 to 40 in.
mass	0.05 to 10,000 g
surface roughness	to 125 μ inch
roundness	0 to 12 in. diameter
thread form	most pitches



Calibration adjustments on an oscilloscope plug-in.



Adjusting speed control potentiometers to initial settings in preparation for running an absolute calibration on accelerometers mounted in a Genisco Model 1068 Centrifuge.

Major resources

- Automated microwave calibration system, automated resistance calibration system, high-voltage system, high-accuracy dc measurement system, high-accuracy ac measurement system, and impedance measurement systems. A system that provides frequency traceability directly to the National Institute of Standards and Technology (NIST), automated frequency calibration systems (designed and built by Sandia) that can calibrate up to 20 instruments at a time. Automated multimeter calibration systems.
- Systems for calibration
 - of general-purpose instrumentation for ac and dc voltage, current, and resistance
 - of temperature measuring and readout devices
 - and repair of oscilloscopes.
- Temperature standards, baths, and chambers, a state-of-the-art automated system for temperature and humidity measurements, and an automated system for calibration of multiple thermocouples.
- King-Nutronics calibrator, Ashcroft deadweight tester, Sandia-designed high-pressure rack, MKS Baratron Heads, Ruska DDR 6000 high-pressure stand, PCB pulse calibrator, Impac Tower, centrifuges, drop ball shock tester, Sierra Cal-Bench, and Flow Systems, Inc. sonic nozzle system. Use computer to control dynamic pressure calibration capability and most processes.
- Zeiss UPMC 550 coordinate measuring machine, universal measuring machines, OGP optical comparator, surface analyzers, gage block comparator, and specialized optical measuring equipment.

Selected accomplishments

- Developed a blackbody source for optical pyrometer calibration.
- Perform dynamic pressure measurements.



Sandia National Laboratories

SAND-91-0744/7400/f-ia

Metals



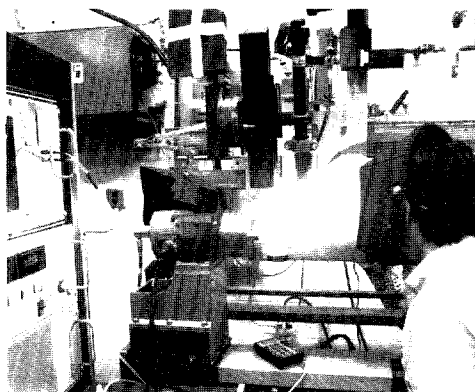
Wax pattern used to produce ceramic mold for casting stainless steel.

Sandia's Metallurgical Processing Laboratory focuses on small-quantity prototype parts for a wide variety of projects. Diverse fabrication techniques and processes are available, including forging, casting, welding, and heat treating, as well as a pattern and model shop. Our staff and tradesmen support these capabilities to provide a full range of services to our customers: design, fabrication, inspection, and acceptance testing. Our primary efforts include

- Design and production of investment, sand, and permanent mold castings.
- A full range of welding and heat treatment capabilities.
- A wide variety of coating and plating processes.
- Detailed process specifications for a wide range of alloys to meet the demanding requirements of our customers.

Capabilities

- Employ high energy density (electron beam, laser, etc.) and conventional welding processes with a full range of inspection and testing capabilities.
- Cast aluminum, lead, and other non-ferrous metals with sand or permanent molds.
- Produce precision investment castings in complex shapes from various alloys, including vacuum-cast, precipitation-hardened stainless steels.
- Apply coatings (enamels, epoxies, acrylics, lacquers, Teflons[®], polyurethanes, silicones, solid-film lubricants, and ablation films) to prototypes, models, test units, and experimental systems.
- Perform chemical and mechanical cleaning, alodining, precious metal plating, electroplating, electroless plating, and matrix studies for process development.
- Produce patterns for foundry use, wood models or mockups, and special shipping and storage containers.
- Perform unique developmental coating work in both organic and inorganic surface modification technologies. These include precious metal plating, electroforming, anodizing, electrophoresis, sprayed organic paint finishing, powder coatings, and special surface preparation techniques.



Weld schedule development for the AL-SX shipping container.



Welding with the shielded metal arc process on a high-pressure (1500 psi) test vessel.

Major Resources

- Computer-controlled electron beam, CO₂, and solid-state laser welders.
- State-of-the-art dual-station 300 kW induction melting facility with an environmentally safe aluminum degassing system that uses inert gas instead of chlorine.
- A precision ceramic mold-making facility for producing complex investment castings of various alloys, including vacuum casting.
- A full range of metallurgical processing equipment: furnaces (air, inert gas, vacuum fluidized bed, and salt baths), quench tanks, deep freeze, and large sandblast room.
- Extensive inventory of certified weld filler metals for both gas tungsten and gas metal arc welding processes.
- Complete pattern and model-making equipment.

Selected accomplishments

- Investment casting of prototype and production metal housings has saved over \$4 million relative to conventional machining processes.
- Received patent for precision wire feeder for use with CO₂ laser welder.
- Welded and inspected prototype low-level nuclear waste shipping containers (such as TRUPACT and NUPACT).
- Modified the design to enhance manufacturability and fabricated a field platform for treaty verification hardware for use in the USSR.
- Fabricated 800-lb aluminum castings for mobile camera bases for the US Air Force and other customers.
- Fabricated and inspected reentry vehicles and provided technical assistance to Eglin Air Force Base fabrication facility.
- Developed fixturing and weld processes for fabrication of 1-mil tantalum foil envelopes.
- Developed processes and wrote specifications for a wide range of coating and plating applications: special light-sensitive organic coatings for satellite hardware, heat-absorbing ablative coatings to rocket bodies for testing programs, special coatings on weapon bodies that can withstand extreme environments, fabrication of unique shapes using electroforming techniques, and processing methods for electroplating black chrome coatings on solar collector tubes.



Ceramics



High-quality prototype electronic components are assembled and inspected prior to developmental testing.

Sandia's Ceramic Processing Laboratory provides a wide range of processing options for many types and compositions of prototype ceramic components [alumina, lead zirconate titanate (PZT), barium titanate, zinc oxide (ZnO) varistor, and ceramic superconductors]. Specifically, we

- Formulate and produce tailored polycrystalline ceramic compositions by conventional mixed oxide or by advanced chemical preparation technology.
- Fabricate a variety of prototype electronic and structural ceramic components.
- Determine key processing parameters related to ceramic powder preparation, consolidation, densification, and assembly to optimize the properties of the final ceramic component.

Capabilities

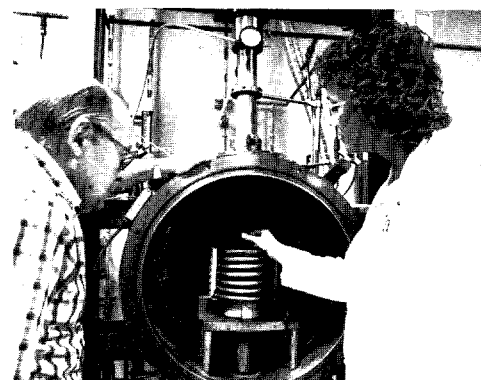
- Fabricate prototype ceramic components to support the design and test phases of a wide range of Sandia projects.
- Interface with Sandia designers and external ceramic vendors to assure that appropriate materials and specifications are selected to meet customer needs at minimum cost.
- Develop new chemical preparation processes for ceramic powder production; perform process development needed to scale up laboratory research processes.
- Provide an alternative production capability and improved processing for ferroelectric ceramics.
- Fabricate prototype alumina structural or insulating components with rapid turnaround time.
- Develop multilayer ceramic-metal devices based on the tape casting of thin (0.001- to 0.080- in.) flexible ceramic layers and associated thick-film technologies.
- Produce fully dense refractory ceramics or composites by hot pressing at temperatures up to 1800°C in controlled atmospheres (vacuum, air, or inert gases).
- Employ powder consolidation methods such as uniaxial and cold isostatic pressing, slip casting, and colloidal filtration to shape form ceramic parts.

Major resources

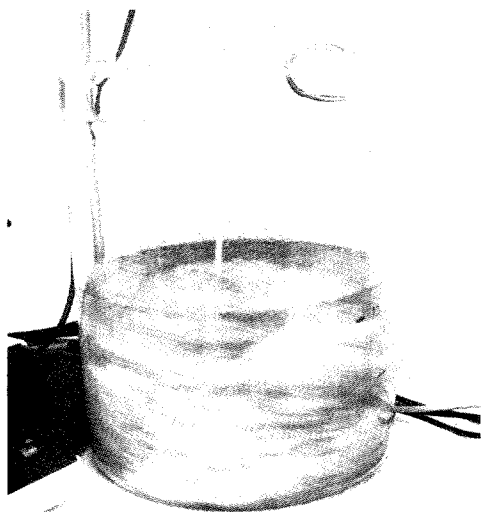
- Clean room facilities designed for the chemical preparation and processing of ceramic materials.
- Multilayer ceramic processing facility for developing advanced electronic ceramic components.
- "Pilot-scale" ferroelectric powder and component processing facility.
- State-of-the-art powder consolidation equipment, sintering furnaces, and hot presses.
- Prototype ceramic machining and component assembly equipment.



The ceramic finishing process is critical because mechanical properties of ceramics are greatly affected by surface treatment.



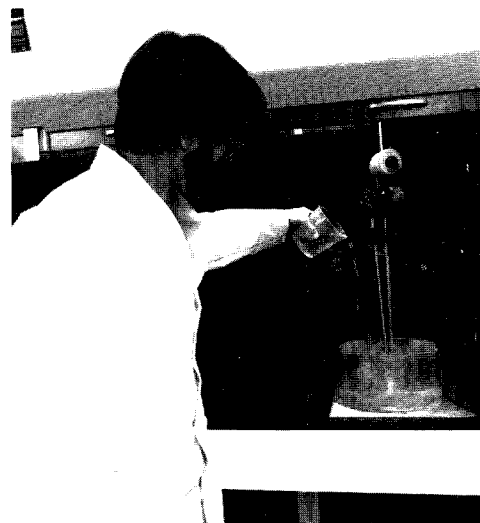
The hot pressing process is used to obtain very high density ceramic specimens.



Superior varistor materials are produced using a batch-type chemical preparation process.

Selected accomplishments

- Converted a laboratory chem-prep technique for producing ZnO varistors into a full-scale manufacturing process by carefully tailoring the process.
- Scaled up a continuous precipitation process for preparation of high-purity homogeneous ceramic superconductor ($\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$) precursor powders.
- Developed an organic system for use in the tape casting of oxide, nitride, metal, and glass powders.
- Developed new formulations for the fabrication of large, crack-free multi-layer PZT-Pt devices.
- Developed a process to fabricate Al_2O_3 -Mo electronic packaging.
- Developed a precision high surface finish metallized alumina to vaporize lithium for particle beam fusion energy experiments.
- Supported production schedules by serving as an alternate production site for ferroelectric components.
- Developed prototype processes for radioisotopic thermoelectric generators and for lead lanthanum zirconate titanate (PLZT) electro-optic ceramics.
- Helped establish profitable product lines at industrial vendors for four of the processes developed here at Sandia.



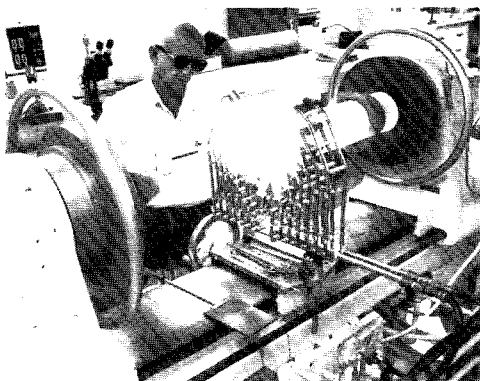
Chem-prep varistor precursor material is prepared by precipitating the metal ions as an insoluble species.



Sandia National Laboratories

SAND-91-0744/7400/f-1a

Glass



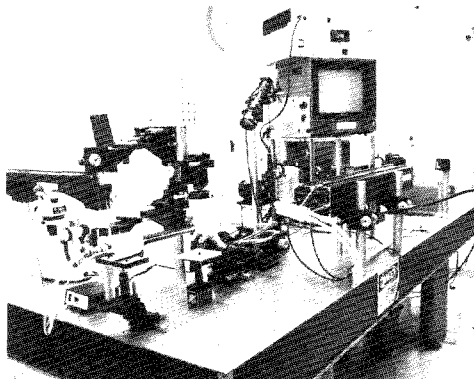
Forming the end of a quartz tube with a carbon shaping rod.

Sandia's Glass Processing Laboratory performs a wide variety of both traditional and highly specialized glass processes. We provide glass and glass-ceramic products to meet the demanding requirements and specialized needs of our customers. Specifically, we

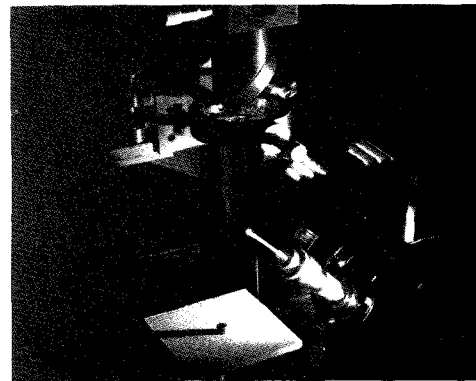
- Formulate and produce glass and glass-ceramic compositions by conventional high-temperature melting or low-temperature chemical polymerization (sol-gel technique).
- Establish key processing parameters (such as annealing and crystallization temperatures); determine and control residual stress in thin films and thick glasses; analyze failures; and measure physical properties (such as thermal expansion, density, viscosity versus temperature, glass transition temperature, and index of refraction).
- Fabricate a wide range of glass apparatus for electronic, vacuum, and chemical applications, including quartz semiconductor glassware.
- Fabricate prototype electronic and specialty components that incorporate glass or glass-ceramic to metal seals.

Capabilities

- Produce hermetic glass or glass-ceramic to metal seals for a wide variety of electronic components.
- Perform a full range of forming techniques, including casting, pressing, and spinning.
- Chemically strengthen glass to customer specifications.
- Fabricate vacuum glassware, backfill with specified gas, and analyze using mass spectrometry.
- Deposit thin glass films with controlled porosity using the sol-gel process.
- Machine ultra-low-density glass foams (aerogels) prepared by sol-gel processing.
- Perform low-temperature field-assisted bonding of glass to semiconductor materials.
- Apply conductive coatings (such as silver, tin, gold, and platinum) by wet chemical and thermal processes.
- Assess component structural design by performing finite-element stress analysis.
- Machine specialized fixtures and molds in the laboratory.
- Continuously monitor oxygen partial pressure and dew point of furnace atmospheres.



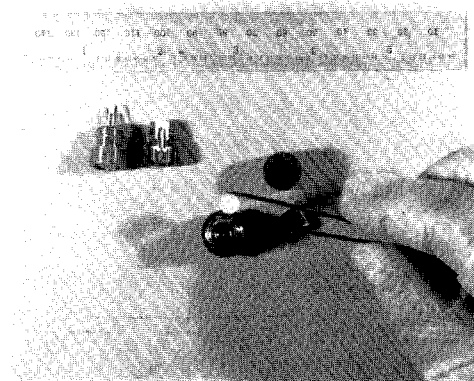
50 W CO₂ Laser Sealing Facility. The image shown on the monitor is of a molten glass rod heated by the laser.



Close up of the laser heating of the glass rod prior to sealing the next assembly.

Major resources

- High-temperature (1700°C) glass melting furnaces with either resistance or induction heating, with capacity up to 15 kg.
- Class 1000 clean room for the application of sol-gel thin glass films by spinning and dipping methods.
- Differential thermal analyzer, expansion and contraction dilatometer, beam-bending viscometer, computer image-enhanced polarimeter, and thin-film stress and thickness interferometers.
- Microprocessor-controlled hydrofluoric acid etching and cleaning station.
- Microprocessor-controlled large-capacity quartz annealing furnace.
- Precision glass lathes for shaping soft glasses, borosilicate glasses, and fused quartz.
- Microprocessor-controlled batch and traveling belt furnaces that can be run with inert atmosphere or specified cover gas for glass-metal seal fabrication.
- Computer-controlled, 50 W CO₂ laser sealing station.



Inserting the glass preform into Inconel 718® metal shell. Cutaway of finished part is shown at upper left.

Selected accomplishments

- Developed prototypes for numerous electronic glass and glass-ceramic weapon components that are used in severe environments (actuators, batteries, microminiature connectors, detonators, fiber-optic devices, sensors, and x-ray tubes).
 - Patented several high-expansion glass-ceramics for sealing to high-strength, corrosion-resistant alloys.
 - Developed sol-gel glass coatings for antireflective glass and plastic surfaces for solar energy collectors.
 - Invented sol-gel protective coating and an aerogel-phosphor composite for radioluminescent light sources and power applications.
 - Produced quality melts of highly specialized glass compositions, including tellurium- and tungsten-based glasses, aluminum-sealing glasses based on phosphorus and germanium, and a variety of fluoride glasses.
 - Invented a family of corrosion-resistant sealing glasses for use in ambient-temperature lithium batteries.
 - Developed novel techniques for making hermetic seals (field-assisted bonding and laser sealing).
- Provided design and process development for pyrotechnic devices for Los Alamos National Laboratory, NASA, and Westinghouse Electric.
- Developed optical feedthroughs for laser diode ignition of pyrotechnics and for single-crystal quartz resonators.



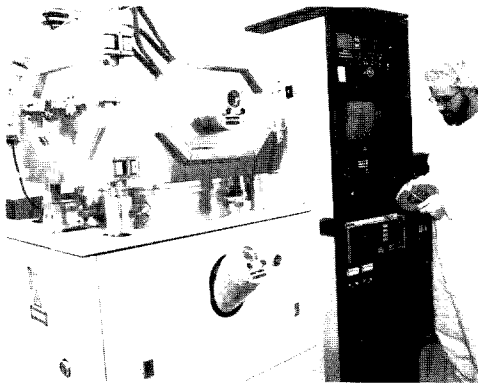
Mounting of glass specimen for differential thermal analysis.



Sandia National Laboratories

SAND 91-0744/7400/f-1a

Thin Film and Brazing



Electron beam evaporator state-of-the-art computer-controlled thin-film deposition system.

Sandia's Thin Film and Brazing Laboratory's diverse equipment and staff allows us to meet a wide range of material process and hardware requirements. We have state-of-the-art equipment for electron beam evaporation, sputtering, plasma-enhanced chemical vapor deposition (PECVD), and brazing. Specifically, we

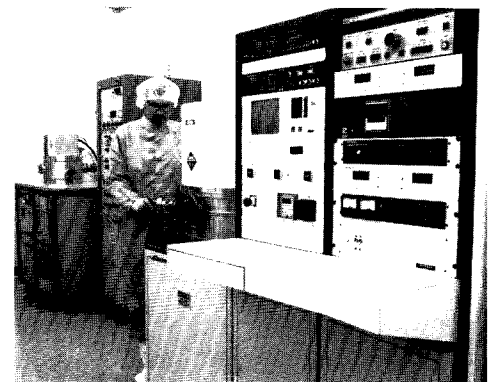
- Deposit many types of thin films for a broad range of hardware and components using processes such as physical vapor, chemical vapor, and sputtering deposition.
- Join metals by brazing, soldering, and diffusion bonding in vacuum, hydrogen, and inert atmospheres.
- Metallize ceramic surfaces for metal-to-ceramic or ceramic-to-ceramic bonding, metallurgical barriers, and compatibility with mating surfaces.
- Clean metal and ceramic surfaces for vacuum devices by chemical processes, vapor degreasing, and high-temperature firing in vacuum, hydrogen, and inert gases.
- Provide short-term prototype fabrications (including specialty fixture development) for unique applications in thin film and brazing.

Capabilities

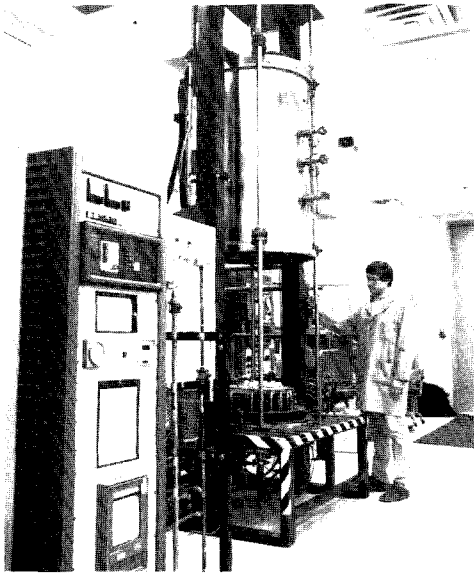
- Routinely sputter over 25 elements as well as numerous compounds, glasses, and metal oxides.
- Deposit diamond-like carbon, Si_3N_4 , and SiO_2 films and are pursuing a program to sputter-deposit high-temperature superconducting materials.
- Employ wet and dry hydrogen and inert gas processing furnaces for state-of-the-art brazing and metal oxide reduction up to temperatures of 1100°C , particularly for stainless steels, nonferrous materials, high-temperature alloys, and refractory metals.
- Use high-vacuum ($<10^{-6}$ torr) furnaces for treatments up to 1600°C .
- Perform special bonding operations (such as field-assisted bonding and unique soldering processes).
- Utilize processing workstations with better than Class 1000 clean room conditions for sputter and chemical vapor depositions that require high purity and contamination control.
- Have engineering expertise to develop unique deposition systems and furnaces to meet specific customers requirements including design, fabrication, instrumentation, and control.
- Analyze desorption of materials under vacuum (10^{-7} torr) at 1000°C and higher, potentially at temperatures up to 2200°C .
- Manufacture vacuum gauges and other vacuum instrumentation for special applications.
- Design and manufacture fixtures for brazing and high-temperature treatments.
- Deposit optical-quality coatings.

Major resources

- Radio frequency and direct current (planar and magnetron) sputter deposition systems.
- Physical vapor deposition systems using electron beam and resistive evaporators.
- High-vacuum ($<10^{-6}$ torr), wet and dry hydrogen, and inert gas processing furnaces.
- PECVD systems.
- Better than Class 1000 clean room for deposition processes that require high purity and contamination control.
- Ultrahigh vacuum and controlled-atmosphere diffusion bonding systems.
- CO_2 cleaning system.
- Ultrahigh vacuum and controlled-ambient hot presses with a temperature range up to 1500°C and tens of tons load capacity.



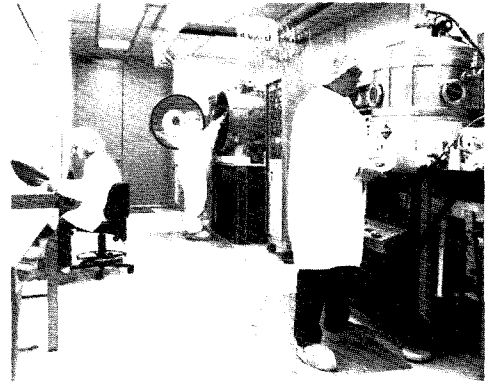
Sputtering (front) and chemical vapor deposition (back) state-of-the-art computer-controlled thin-film deposition systems.



Large hydrogen brazing furnace.

Selected accomplishments

- Fabricated short-term low-quantity prototypes in the brazing and thin-film deposition areas to support satellite hardware, high-vacuum devices, test programs, and energy-related material and process development.
- Brazed together complex geometries and performed thermal processing of materials for fusion energy projects.
- Produced contact metallizations for the photoconductive silicon device development programs to evaluate compatibility and environmental issues.
- Used desorption studies to reduce premature and post-discharge breakdown of vacuum tube devices.
- Developed a short braze cycle (1087°C to 1990°C for 6 to 7 s) to control copper migration during brazing for improved structural integrity.
- Successfully deposited contact metallizations on HgI_2 crystals.
- Used CO_2 to dissolve organics and to remove particulate contaminants from ceramic piece parts for vacuum devices.



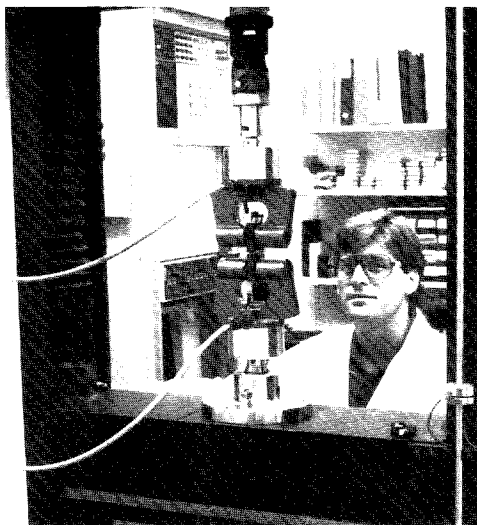
Sputtering and evaporating systems for prototype thin films (2 of 10 processing stations).



Sandia National Laboratories

SAND 91-0744/7400/f-ia

Polymers, Adhesives, and Composites



A peel test on a sample of OFHC copper/60Sn40Pb/A2611 flux.

Sandia's Polymers, Adhesives, and Composites Laboratory provides material and processing expertise and prototype fabrication capabilities for a wide variety of polymer applications. We practice concurrent engineering with designers who are involved in the application of thermosetting, thermoplastic, and composite materials. We routinely use these materials to join, package, and provide structural members to satisfy demanding electrical, mechanical, and environmental design requirements. Specifically, we

- Formulate resin systems for a wide range of prototype applications: these resin systems include epoxies, silicones, and polyurethanes.
- Perform a broad range of material characterizations, including mechanical testing, surface analysis, thermal property measurement, electron microscopy, spectrometry, and wet chemical analyses.
- Fabricate a wide variety of prototype parts using thermoforming, bonding, filament winding, coating, encapsulating, milling, compression molding, and transfer molding operations.

- Perform failure analyses: these include encapsulant and adhesive removal as well as use of metallographic and scanning electron microscopic techniques.

Capabilities

- Coat with organic materials such as epoxies, urethanes, and silicones using spray, brush, or dipping techniques.
- Employ anaerobic, aerobic, and ultraviolet (UV) curing methods on a wide range of geometries for bonding operations.
- Prepare surfaces by plasma cleaning, sandblasting, etching, and priming.
- Encapsulate using foams, elastomers, and rigid resins (typical resins used are epoxies, silicones, and polyurethanes).
- Fabricate polymer composites using hand lay-up, laminating, and filament winding. These materials are composed of fibers in an epoxy, polyimide, or silicone resin matrix.
- Thermoform a variety of thermoplastic materials such as polycarbonate, polymethyl methacrylate, polypropylene, and polystyrene.
- Perform compression and transfer molding of all types of geometries using thermosetting resins such as epoxy, silicone, phenolic, and polyimide.
- Perform rubber milling of all types of elastomers such as silicones, butyl, and neoprene.

Major resources

- A staff, with training from PhD through Tradesman level, which allows us to support projects across the entire spectrum of polymer issues.
- Processing equipment: dry wall for spraying, sandblasters, ovens, autoclaves, vacuum casting equipment, thermoformer, rubber mill, filament winder, plasma cleaner, vapor degreaser, laminator, and transfer and compression molding presses.
- Analytical equipment: Fourier transform infrared spectrometer for material identification, thermal analysis equipment such as differential scanning calorimeter, thermomechanical analyzer, and thermal gravimetric analyzer for glass transition, coefficient of thermal expansion, specific heat, reaction kinetics, and thermal decomposition analysis.
- Mechanical properties: load frames, dynamic mechanical thermal analyzer, and temperature chambers for determining mechanical dampening, thermomechanical properties, elastic moduli, mechanical strength, and fracture toughness.



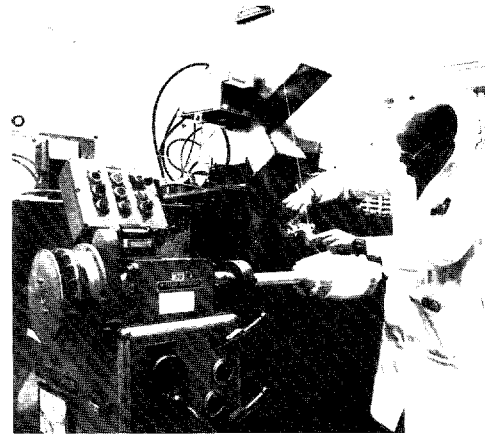
A polycarbonate flash goggle housing.



A 30-mg EN8 (polyurethane) sample for thermal gravimetric desorption of EC7R, a new nonchlorinated cleaner.

Selected accomplishments

- Developed a UV-cured coating that eliminates the use of hazardous solvents found in many other coatings.
- Developed new epoxy curatives to replace existing hazardous (carcinogenic) materials.
- Introduced a novel, quantitative torque adhesion test that measures adhesion of thin films or strengths between material interfaces.
- Developed an experimental technique to measure residual strains that develop during potting, curing, and thermal cycling of various assemblies. This method was successful in verifying the thermo-mechanical properties of encapsulants used in finite-element analyses.



A McClean-Anderson filament winder is used to fabricate a flexible shroud from Dupont Kevlar and a thermal barrier silicone resin.



Sandia National Laboratories

SAND 91-0744/7400/f-ia

Machining



Precision multi-axis, right-angle milling operation.

Machining's diverse team members work one-on-one with designers and become involved early in the design process to allow for Design for Manufacturability. We also provide technical liaison and work with engineers, using their sketches as well as drawings to fabricate a variety of prototype components and assemblies.

Capabilities

- **Project Machining.** Machine and assemble prototype components for various Sandia programs.
- **Miniature Machining.** Start-to-finish fabrication of very complex miniature (0.0002-in. tolerances) mechanisms.
- **Heavy Machining.** Fabricate and assemble prototype hardware that exceeds 12 in. in diameter or 18 in. in length.
- **Sheet Metal.** Provide mechanical assembly services. Design and fabricate special tooling and fixtures to meet customer requirements and cut supplied materials to specifications. Design and fabricate a variety of complex assemblies and components, such as precision sheet metal devices and hot metal forgings.

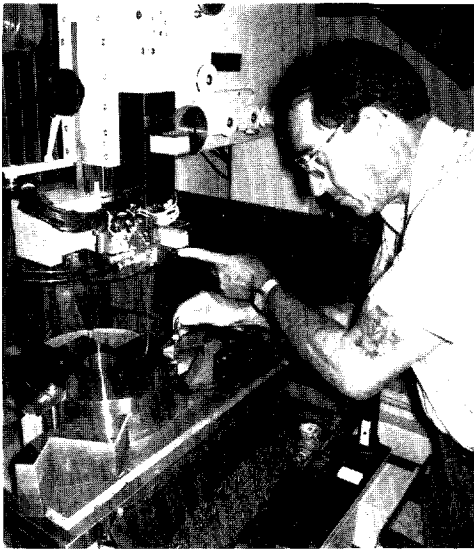
- **Explosives Machining.** Provide support for explosive test projects by machining explosives into various configurations as well as assemble and disassemble (postmortem) devices containing explosives.
- **Composites and Surface Finishing.** Lapping and polishing to microinch tolerance finishes and flatness in light bands, precision grinding of many exotic materials (such as quartz, sapphire, boron nitride, and tungsten), and machining of composite materials (such as carbon, silica phenolic, and fiberglass).



Lapping several fiber optic cables

Major resources

- **Project Machining.** NC milling machines, lathes, and wire-cut electric discharge machines (EDMs). Large Mitsubishi five-axis wire EDM machine. This wire EDM is one of the few large five-axis EDMs located in North America. Four-axis state-of-the-art EDM sinker. The machine is fully NC programmable and will accommodate parts up to 8 in. x 17.7 in. x 8 in.
- **Miniature Machining.** CNC milling machines, jeweler's and CNC lathes, jig bores, ram and wire EDMs.
- **Heavy Machining.** Three-, four-, and five-axis machining centers. Large lathes and boring mills.
- **Sheet Metal.** Press breaks, power rolls, power shears, CNC sheet metal punches, and power forging presses.
- **Explosives Machining.** Lathe, milling machine, hydraulic press, and a Bridgeport milling machine. These machines were modified for machining of explosives and have controls for remote operation.
- **Composites and Surface Finishing.** Surface grinders (capacities from 6 in. x 8 in. to 36 in. x 96 in.), outer-(O.D.) and inner-diameter (I.D.) universal grinders (capacities from 0.050 to 30 in. in diameter), and honing machines. State-of-the-art equipment includes CNC jig grinders (for grinding complex configurations in a wide variety of materials), lapping and polishing machines, and verification inspection equipment.



Traveling wire electrical discharge machining (EDM) of fine features in steel blank.

Selected accomplishments

- Fabricated a full-scale model of a Soviet missile launcher.
- Modified F111B crew module for wind tunnel tests.
- Fabricated two flight test reentry vehicles including the substructure, cover, and nose parts.
- Fabricated a unique and precise five-axis film positioner for taking photographs during wind tunnel tests.
- Fabricated quartz antennas for prototype testing.
- Polished fiber optics for arming devices.
- Machined ceramic components for neutron tube development.

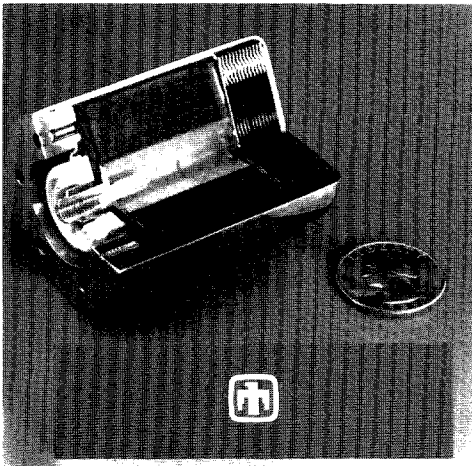


NC jig grinding of features in a precision straight edge.

Manufacturing Engineering

Sandia's Manufacturing Engineering group provides an integrated prototype and production service. Our work includes process development, piece part fabrication, and the assembly of prototype precision components. These include small high-accuracy mechanical assemblies, high-energy capacitors, neutron generators, and rolamites.

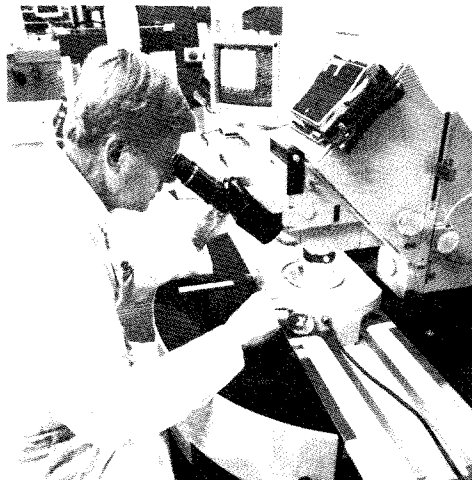
We also design, fabricate, and assemble special (noncommercial) processing equipment. We fabricate and assemble prototype capacitors using winding machines and a fill station that were designed and built at Sandia. Our staff has a variety of skills that includes design, process development, machining, and electronic fabrication.



Sectioned view of a precision component capacitor.

Major resources

- Machine Shop. Three- and four-axis CNC milling machines, electrical discharge machine (EDM), jig bore, lathes, milling machines, and grinders.
- Clean Rooms. Class 1000 and Class 100,000 clean rooms are equipped with a capacitor winding machine, x-ray machine, resistance welder, Instron tester, and Olympus microscope for microphotography that allow us to assemble and test miniature components and electromechanical devices.
- Engineering Laboratory. Capacitor filling machine, ultrasonic welder, leak detectors, and ultrasonic cleaner.
- Capacitor fabrication equipment. Rolamite fill station (silicone fill), computer-controlled Instron tester, high-speed camera.
- Capacitor winding machine. This machine features clutch/motor tensioning mechanisms, closed-loop tension control, precision material velocity and acceleration control, reduced machine stiffness in the film travel direction, low-level industrial and high-level supervisory computer controllers, and an improved human interface.



Mechanical size measurements of a precision part.



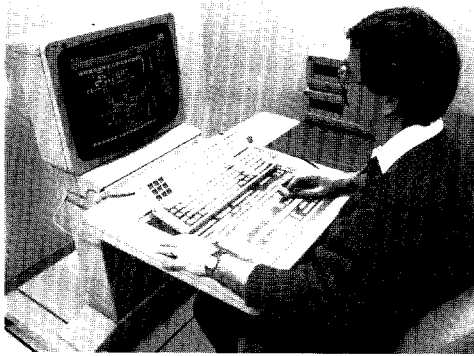
Precision mechanical assembly in clean room.

Selected accomplishments

- Established the capacity to assemble ferroelectric neutron generators using weapon-related processing.
- Developed molds, such as for foam encapsulating battery packs.
- Assisted in the design, process development, and prototype fabrication of perfluorocarbon liquid (Fluorinert (TM))-filled plastic dielectric capacitors.
- Fabricated, assembled, and helped evaluate prototype and development of electromechanical safing and environmental sensing devices. We fabricated and evaluated over 300 miniature precision springs.
- Fabricated, assembled, and provided process development as well as troubleshooting for rolamites with the electrically grounded steel-case design.
- Managed major projects, including hardware fabrication and tracking, manufacturing review, cost analysis, production agency liaison, and inspection.

Computer-Aided Manufacturing (CAM) and Stereolithography

Stereolithography activity provides computational, networking, and software resources as well as desktop manufacturing. Our experience includes computer systems software, real-time process control, data acquisition, database management, manufacturing processes, numerical control (NC) programming, computer graphics, mechanical design, and networking.



Developing hybrid microelectronics circuits using a CAD/CAM system.

Capabilities

Parts Programming

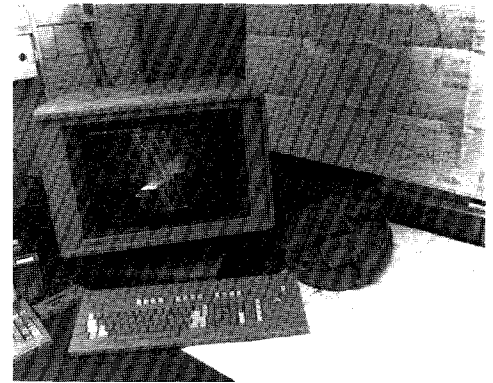
- Review the engineering design for accuracy and clarity.
- Propose design changes to improve manufacturability.
- Devise process plans with the concerned craft specialists.
- Design fixturing for securing the part in each setup position.
- Prepare the CAD database or construct the geometry for producing the part and inspection paths.
- Program the tool paths prescribed in the process plan.
- Modify tool paths for production-ready status.

Software Development

- Understand requirements.
- Develop prototype software and hardware to determine the feasibility for completing the requirements.
- Define the interfaces, determine the database information and structure, and design the programs.
- Generate and test the computer codes.
- Develop regression testing techniques and accumulate a suite of test programs.
- Install software and train users.

Major resources

- VAX 8550 computer and Tektronix workstations with ANVIL-5000 CAD/CAM software.
- Intergraph workstations and software for electrical CAD/CAM.
- 3D Systems laser stereolithography model SLA-250.



CAD/CAM system for NC program development and verification.

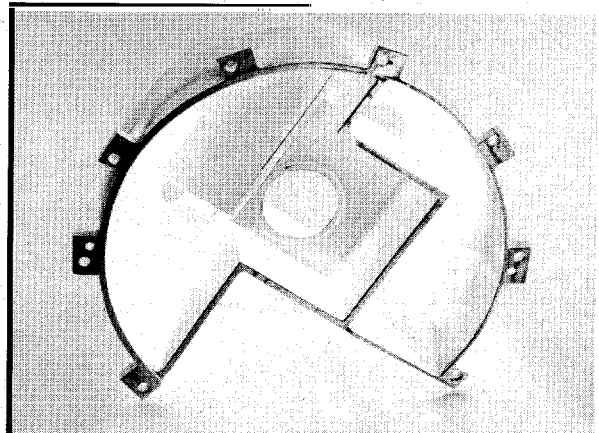
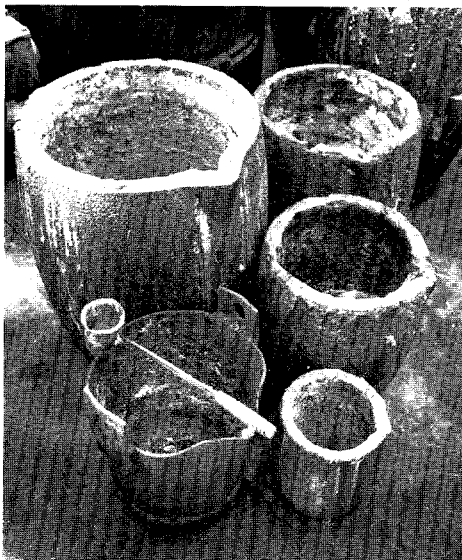
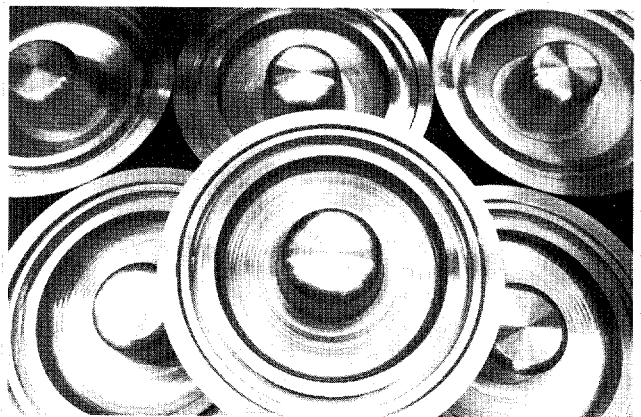
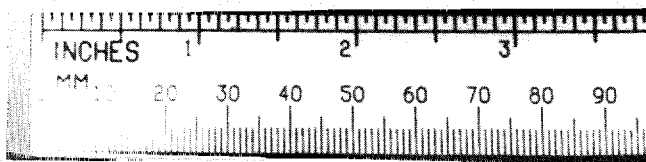
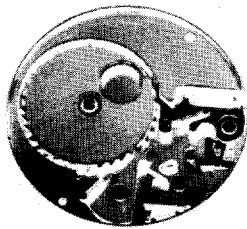
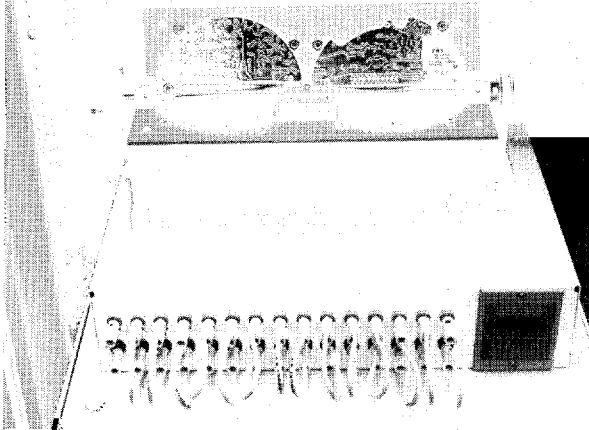
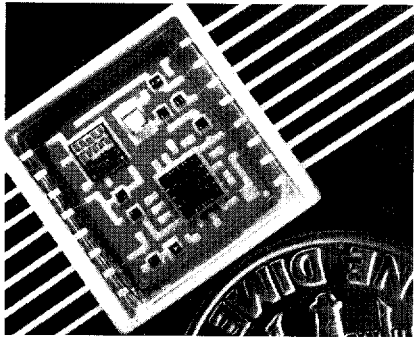
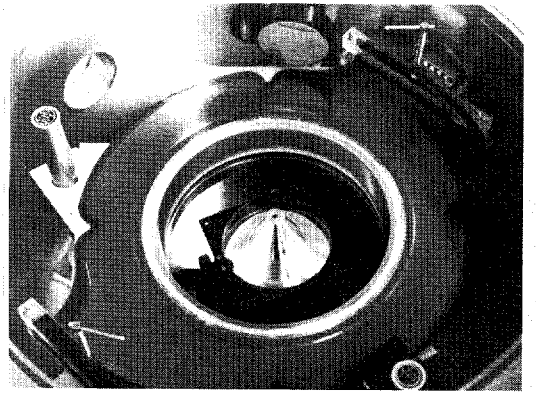
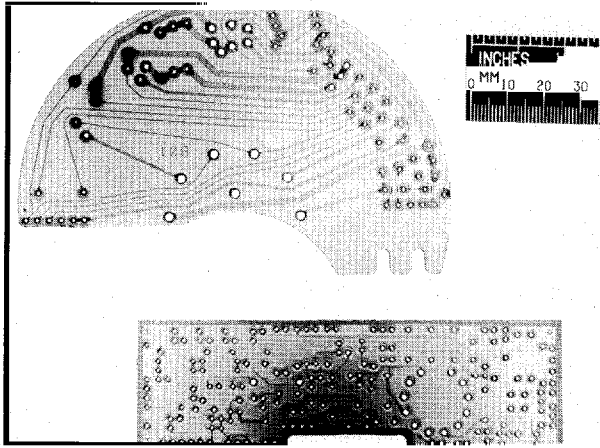
Selected accomplishments

- Programmed NC machines (from lathes to five-axis machining centers) to produce complex prototype mechanical hardware. We use computer graphics solid modeling techniques to verify tool path programs. The craft specialists are also trained to use the CAD/CAM system, thereby enhancing our rapid prototyping capabilities.
- Developed prototype expert system software that uses the ANVIL-5000 engineering design databases to assist in the programming of drilling and milling machines. The software has the demonstrated capability to reduce current programming times by 80 percent.
- Established a computer system and purchase order (PO) database for retaining contractor performance (cost, quality, schedule). PO data is collected from technical fabrication coordinators, purchasing clerks, and receiving personnel to provide timely status reporting.
- Interfaced an Intergraph electrical CAD system with manufacturing equipment and the Sandia Central Computing Network to provide CAD/CAM integration.



Stereolithography fabrication of prototype parts and patterns.







**Sandia
National
Laboratories**

Marty Noland

Janise Baldo

Gene A. Clardy

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, or any agency thereof or any of their contractors or subcontractors.

[illegible]

Sandia National Laboratories

Albuquerque: (505) 844-8035
Livermore: (415) 294-2118